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Corn *(Zea mays)* and Soybean *(Glycine max)* Tolerance to Broadcast Flaming

Teixeira Z. Heverton

Santiago Ulloa
University of Nebraska-Lincoln, smulloa@bigred.unl.edu

Avishek Datta
University of Nebraska-Lincoln, adatta2@unl.edu

Stevan Z. Knezevic
University of Nebraska-Lincoln, sknezevic2@unl.edu

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Cover Page Footnote

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1. Introduction

Recent developments, including an increasing number of herbicide-resistant weeds, higher costs of herbicides, and more concern about pesticides in the environment, have resulted in a renewed interest in flaming for weed control (Wszelaki *et al.* 2007). For these reasons, weed scientists are studying alternative and integrated systems of weed management to reduce herbicide inputs and impacts (Rifai *et al.* 2000). Several studies have demonstrated the beneficial effect of flaming for weed control in major vegetable crops (Ascard 1994, 1995; Lague *et al.* 1997). However, the response of most agronomic crops such as corn and soybean to flaming was not investigated. Most flaming studies were actually conducted in organic farming systems. Organic farmers rank weed control as the number one problem limiting production (Walz 1999). Very few organic herbicides are approved for organic farming, labor costs associated with hand weeding are high, and repeated cultivation used by most growers increases the chance of soil erosion, thus, alternative methods of weed control are necessary (Wszelaki *et al*. 2007; Riemens *et al*. 2007).

Flaming could be an essential component of a multi-faceted weed control program, which could lessen the reliance on herbicides, hand weeding, and/or mechanical cultivation (Wszelaki *et al.* 2007). Flaming may provide added benefits, such as insect or disease control (Lague *et al.* 1997). Therefore, the response of the major crops to flaming needs to be determined, with the intention to optimize the use of flaming as a weed control tool. The objective of this study was to provide some basic information on corn and soybean tolerance to broadcast flaming.

2. Materials and Methods

A field experiment was conducted at the Haskell Agricultural Laboratory near Concord, NE (lat 42.37°N, long 96.68°W) in a randomized complete block design with six treatments (propane rates) and three replications. The experimental site was cultivated on August 10. Plots (2.1 m wide × 3.8 m long) were planted to corn and soybean on August 17 by using manual push-planters, as a single row for each species in a 40 cm row spacing. Weeds inside the plots were controlled by hand weeding. Flaming was done on September 9, which corresponded to the V5 stage in corn and V3 in soybean, with plant heights of 25 and 8 cm for corn and soybean, respectively. Treatments were applied with a custom built flamer mounted on an ATV, which was driven across the crop rows. The flamer used propane as a source for combustion. There were four burners (LT 2 × 8) mounted

30 cm apart. Burners were positioned 20 cm above the soil surface and angled back at 30˚. Flaming treatments were applied using a constant speed of 6 km/h. Propane pressures included: 0, 69, 207, 345, 483 and 620 kPa, corresponding to 0, 10, 30, 50, 70 and 90 PSI. Combining pressure and speed, the rates of propane applied were: 0, 12, 31, 50, 68 and 87 kg/ha. Weather conditions included: wind speed of 11 km/h (direction NNW), air and soil temperatures of 22 °C, and relative humidity of 46%.

Crop injury was rated visually at 3 hours, 1 day after treatment (DAT), 3 DAT, 7 DAT and 14 DAT using a scale of 0 (no crop injury based on untreated plots) to 100 (plant death). In addition to visual ratings, biomass samples were taken at 14 DAT. One linear meter of corn and soybean plants were clipped from each of the treated plots. Samples were dried at 50 °C and dry matter (DM) was determined. These results were transformed to relative biomass, where the plant DM is expressed on a relative scale from 0 to 100, as a percentage of untreated plants (Knezevic *et al*. 2007).

Visual estimations and biomass data were analyzed for each rating date utilizing a log-logistic function with four parameters (Knezevic *et al.* 2007):

$$Y = C + \{D - C / 1 + \exp[B(\log X - \log E)]\} \quad [1]$$

where Y is the response (e.g., visual quality), C is the lower limit, D is the upper limit, B is the slope of the line, X is the propane dose and E is the dose giving a 50% response (also known as ED50). Curve fitting was done by non-linear regression using the least squares method. All statistical analysis and graphs were performed with **R** program (R Development Core Team 2006) utilizing the Dose Response Curves (*drc*) statistical addition package (Knezevic *et al.* 2007). The values of ED5 (effective dose that provided 5% injury), ED10 (10% injury) and ED20 (20% injury) were determined from the curves and used as measures of the level of crop damage by flaming treatments.

3. Results and Discussion

In general, corn was more tolerant to flaming than soybean. Soybean was very susceptible to flaming, resulting in similar propane dose response curves regardless of the evaluation time (Figure 1). In general, for soybean the ED values for the visual ratings at any particular level did not change from the first evaluation (3 h after treatment) to the last evaluation (14 DAT). For example, the ED values for 3 h after treatment were 11 kg/ha, 13 kg/ha and 17 kg/ha for ED5, ED10 and ED20, respectively, and these propane rates did not change significantly with time (Table 1). At 14 DAT, only 28 kg/ha propane dose (ED50)

Table 1. Propane doses (kg/ha) that resulted in 5%, 10% and 20% injury of soybean based on the visual ratings from 3 hours to 14 DAT.

Time after treatment	Effective dose of propane (kg/ha)		
	ED5 (SE)	10ED (SE)	ED20 (SE)
3 h	11 (2)	13 (2)	17 (2)
1 DAT	8 (2)	11 (2)	15 (2)
3 DAT	12 (3)	15 (3)	20 (3)
7 DAT	11 (2)	15 (2)	20 (2)
14 DAT	14 (2)	17 (2)	21 (2)

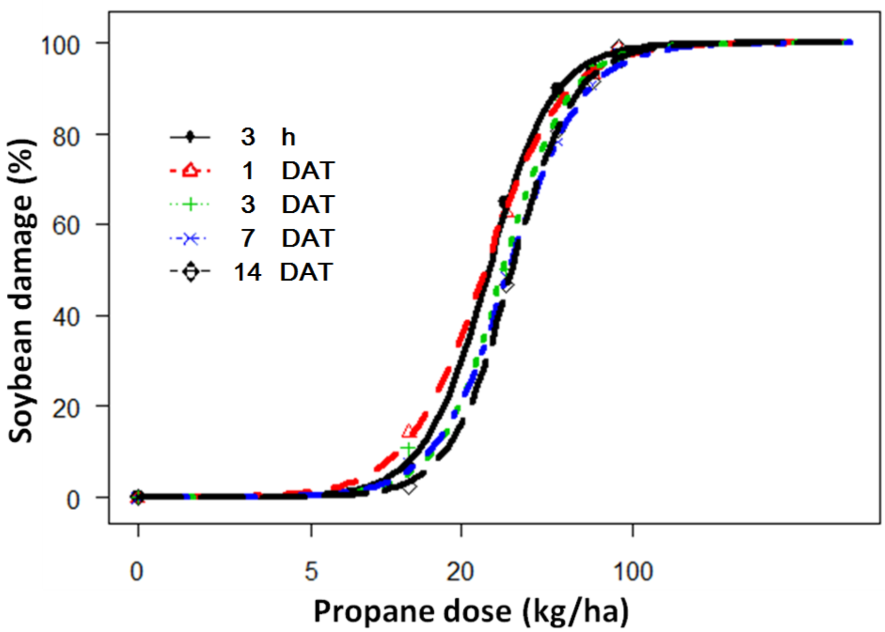

Figure 1. Soybean damage as influenced by propane dose based on visual injury ratings from 3 hours to 14 DAT. Each data point represents a mean of 3 replications. Data was fitted to log-logistic equations with four parameters.

was sufficient to produce 50% visual damage in soybean (Table 2); any higher rates would have caused more injury. These results indicated that soybean was not able to recover from the early injury caused by flaming.

Table 2. Regression parameters for each evaluation time describing the visual response of soybean plants to propane flaming (Figure 1). Regression parameters were estimated using Equation 1.

Evaluation timing	*B*	*D*	*ED50*[a]
3 h	-3.7	99	20
1 DAT	-2.2	103	20
3 DAT	-2.7	105	23
7 DAT	-2.8	99	22
14 DAT	-3.3	96	28

[a]*ED50*, the dose giving a 50% visual damage.

There were significant differences in ED values over time for corn (Table 3), resulting in different propane dose response curves (Figure 2). This suggests that corn was able to recover after flaming. Values of ED5 and ED10 did not differ for the first 4 ratings (3 h to 7 DAT, Table 3). However, they significantly increased at 14 DAT, suggesting that corn started recovering from flaming after the 7 DAT rating. Faster recovery of corn was more evident with ED20; values of 14, 22 and 46 kg/ha corresponded to evaluation timings of 3 h, 7 DAT and 14 DAT (Table 3). It is interesting to note that the ED50 value for corn at 14 DAT was estimated at > 100 kg/ha, which is greater than the highest propane rate tested in this study (87 kg/ha) (Table 4). These results indicated that higher propane rates caused more visual damage at early evaluation timings, nevertheless, treated corn plants were able to recover since the growing point remained unaffected.

Table 3. Propane doses (kg/ha) that resulted in 5%, 10% and 20% injury of corn based on the visual ratings from 3 hours to 14 DAT.

Time after treatment	Effective dose of propane (kg/ha)		
	ED5 (SE)	ED10 (SE)	ED20 (SE)
3 h	6 (1)	9 (1)	14 (2)
1 DAT	6 (1)	10 (2)	16 (2)
3 DAT	6 (2)	10 (2)	18 (3)
7 DAT	8 (2)	13 (3)	22 (3)
14 DAT	19 (7)	29 (7)	46 (6)

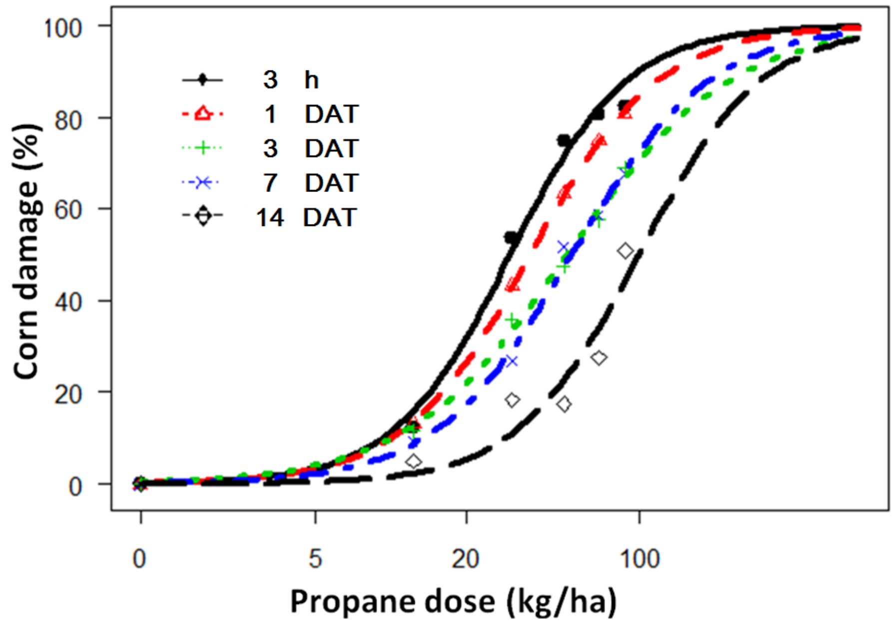

Figure 2. Corn damage as influenced by propane dose based on visual injury ratings from 3 hours to 14 DAT. Each data point represents a mean of 3 replications. Data was fitted to log-logistic equations with four parameters.

Dose response curves based on DM also demonstrated that soybean was more susceptible than corn to flaming treatments (Figure 3). The highest rate of propane used in this study (87 kg/ha) provided about 90% DM reduction in soybean compared with only about 50% in corn (Figure 3).

Table 4. Regression parameters for each evaluation time describing the visual response of corn plants to propane flaming (Figure 2). Regression parameters were estimated using Equation 1.

Evaluation timing	*B*	*D*	*ED50*[a]
3 h	-2.6	92	23
1 DAT	-1.3	93	44
3 DAT	-0.9	75	81
7 DAT	-1.3	122	72
14 DAT	-1.1	155	> 100

[a]*ED50*, the dose giving a 50% visual damage.

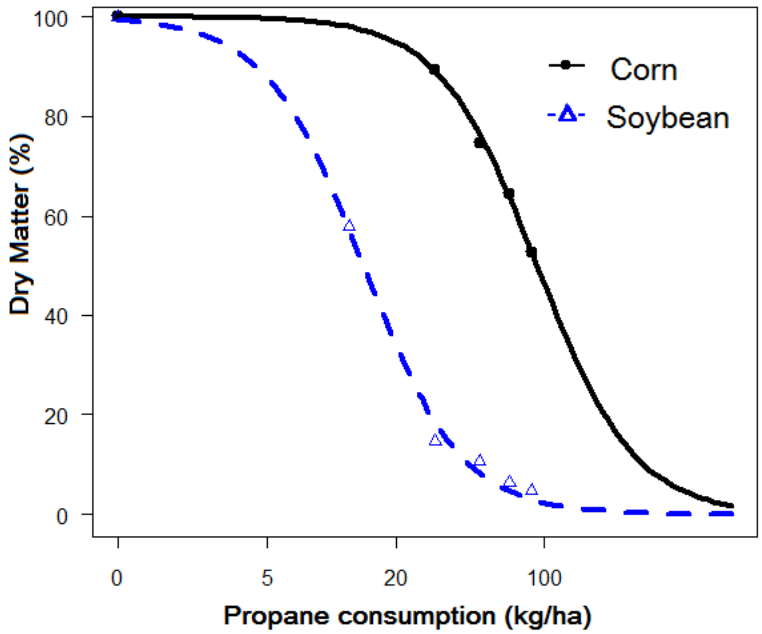

Figure 3. Dry matter (% of untreated) as influenced by the propane dose at 14 DAT. Each data point represents a mean of 3 replications. Data was fitted to log-logistic equations with four parameters.

It is important to note that although soybean and corn were planted at the same time, there was a great difference in height between the two crops. Flaming torches were placed 20 cm above the soil level. This allowed 25-cm-tall corn to have some plant parts out of the range of the flames, while 8-cm-tall soybean was totally exposed to the flames. These findings supported previous studies by Wszelaki *et al.* (2007) who also reported that grasses were more tolerant to flaming than broadleaf species. Corn emerged earlier (data not shown) and grew faster than soybean, and for this reason corn was larger than soybean at the time of flaming. Additionally, the growing point in grassy crops remains below soil surface during early growth stages, protecting it from the flames (Ascard 1995).

4. Conclusions

Although this was only a single-year study, the results clearly demonstrate that soybean flamed at V3 growth stage was more susceptible to flaming than corn at V5 growth stage, suggesting that broadcast flaming perhaps has more potential for use in field corn than in soybean. However, these results may have differed if the flaming was done at different crop growth stages.

Temporary corn injury of as much as 20% was evident with a propane rate of 46 kg/ha. However, such rate was highly efficient in weed control, providing as much as 90% control of broadleaf weeds, including velvetleaf (*Abutilon theophrasti*) and redroot pigweed (*Amaranthus retroflus*) (Knezevic and Ulloa 2007).

High levels of soybean injury suggested also that there is a need to evaluate various timings of flaming procedures relative to the plant crop growth stage, and the positioning of the flame. For example, adjusting the timing of flaming, or flaming inter-row space, as well as positioning flames below the crop canopy (e.g., away from crop's growing point) might be much safer for soybean. Studies are needed to test such hypothesis.

Finally, from the practical standpoint, the obvious concern is that crop injury levels higher than 10% or even 20%, likely will not be acceptable by the organic producers. Many producers will be asking this simple question: "Is the 10% crop injury going to cause 10% yield reduction". Therefore, additional studies are needed to test the relationship between the injury level by flaming, and corresponding crop yields and yield components.

We believe that propane flaming has a potential for use in organic agriculture, particularly with grassy crops like corn, or could be integrated with other non-chemical weed management strategies.

Acknowledgments

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Author Biographies

Heverton Z. Teixeira, B.S., was a visiting undergraduate student from University of Sao Paulo, Brazil. He spent 6 months in the weed science research program of Dr. Stevan Z. Knezevic. This manuscript was part of his Senior Thesis Project.

Santiago M. Ulloa, B.S., M.S., is currently pursuing his Ph.D. in the Agronomy and Horticulture Department at the University of Nebraska–Lincoln under supervision of Dr. Stevan Z. Knezevic. He is working on the research project entitled "Flaming as an alternative weed control method for agronomic crops in organic and conventional productions."

Avishek Datta, B.S., M.S., Ph.D., is Postdoctoral Research Associate under the supervision of Dr. Stevan Z. Knezevic at Haskell Agricultural Laboratory (Concord), Northeast Research and Extension Center, University of Nebraska. His main area of research is crop competition and herbicide tolerance, weed control in wetlands.

Stevan Z. Knezevic, B.S., M.S., Ph.D., is Associate Professor of Integrated Weed Management at the University of Nebraska–Lincoln. His research interests include weed ecology, crop-weed interactions as affected by cropping practices and nutrient management, herbicide technology and systems simulation. Also of current interests are weed control in organic cropping systems, weed control in wetlands and control of problem weeds in Roundup-Ready soybeans.